low molecular weight [~ 2000 daltons (*2*)], the considerations would be much the same as for diffusion of morphogens in embryogenesis, in which case distances $\lesssim$ 100 cell diameters have been estimated (*30*). A clone spanning such a distance would have $N \lesssim 10^6$ cells. An alternative approach is through data on the number of tumor cells required for localized cancer induction with high probability. Numbers of cells between 10^4 and 10^6 are frequently used (*27*). We conclude that N may be in the range 10^3 to 10^6 cells.

An increased rate of inhibitor metabolism by mutant cells would also lead to a locally reduced inhibitor concentration, so that, at least qualitatively, the effects would be similar to reduced secretion and need not be separately considered.

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14 November 1975; revised 26 January 1976

Sex Differences in Cognition: A Function of Maturation Rate?

Abstract. *Regardless of sex, early maturing adolescents performed better on tests of verbal than spatial abilities, the late maturing ones showed the opposite pattern. Those maturing late were more lateralized for speech than those maturing early. Sex differences in mental abilities, it is argued, reflect differences in the organization of cortical function that are related to differential rates of physical maturation.*

Discussions about the origins of sex differences in behavior have usually focused on obvious dichotomies, such as nature versus nurture and male versus female. However, the sexes can also be arrayed along continuous biological dimensions. Examining data from this point of view might yield more information about the mechanisms of sex differences than do dichotomous comparisons of male and female.

One such dimension is maturational rate; females generally attain physical maturity at an earlier age than males (*1*, *2*). Therefore, I hypothesized that this biological variable would be systematically related to mental abilities for which sex differences have been repeatedly demonstrated: (i) verbal ability (fluency, articulation, and perceptual speed), at which females have been reported to excel, and (ii) spatial ability, at which males have been reported to excel (*3*).

Several authors have proposed relationships between verbal and spatial ability and the organization of higher cortical functions. Buffery and Gray (*4*) have argued that earlier and stronger lateralization of language in females facilitates verbal ability and that bilateral representation of space in males facilitates spatial ability. Alternatively, Levy (*5*) has postulated that intraindividual differences between these abilities reflect differences in the degree of specialization of language in the left cerebral hemisphere. That is, bilateral mediation of language increases the probability that language will interfere with spatial processing, which is presumed to be the province of the right hemisphere. Recent data indicating that speech is more lateralized among adult males than females (*6*) are consistent with the Levy hypothesis (*5*).

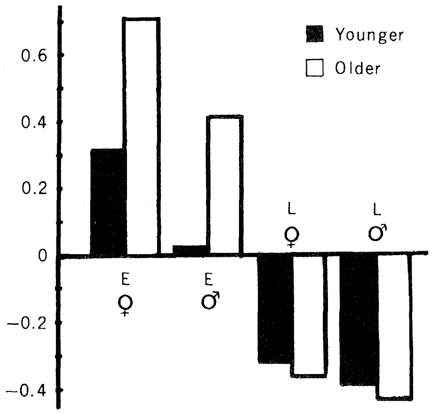

Fig. 1. Mean values of difference scores for each grouping of sex, maturation, and age level. Positive values indicate that the verbal score is greater than the spatial score, and negative values indicate that the spatial score is greater than the verbal score.

In this study, both verbal and spatial performance and lateralization of linguistic processing were examined in relation to sex and maturational rate. Two hypotheses were tested. Along a continuum of rate of maturation, and regardless of sex, (i) so-called early maturers perform better at verbal than spatial ability, and so-called late maturers perform better at spatial than verbal ability; and (ii) early maturers are less lateralized for speech perception than late maturers. The results of the study support these two hypotheses.

A sample of early and late maturing adolescents was selected at two age levels, which were chosen to maximize the observable physical variability and so differed for boys and girls. Girls 10 and 13 years old and boys 13 and 16 years old from a middle-class Caucasian population were examined medically and rated according to the Tanner criteria for staging secondary sexual characteristics, which are a good indicator of general physical growth (*2*). From this population, individuals were selected as early maturers if their chronological age was at least 1 standard deviation below the mean age for their stage of sexual development, and as late maturers if their chronological age was at least 1 standard deviation above, according to norms reported by Marshall and Tanner (*2*). Subjects in the final sample of 80, which comprised ten early and ten late maturing girls and boys at both age levels, were given psychological testing in school (*7*).

Tests for which sex differences in the appropriate direction had previously been reliably reported were used to assess mental abilities (*3*). The Digit Symbol subtest of the Wechsler Intelligence Scale for Children (WISC) (*8, 9*), the Color-Naming subtest of the Stroop Color Word test (*10*), and the Word Fluency subtest of the Primary Mental Abilities (PMA) test (*11, 12*) measured verbal ability; the Block Design subtest of the WISC (*9, 13*), the Embedded Figures test (*14*), and the Spatial Abilities subtest of the PMA (*12, 15*) measured spatial ability.

A dichotic test of phoneme identification measured lateralization (*16*). The stimuli were all possible pairs of the six consonant-vowel syllables, bæ, dæ, gæ, pæ, tæ, and kæ. There were 60 presentations given in two random orders on two different tapes. Subjects heard each tape twice (counterbalanced for ear and channel) and were asked to record the sound they had heard after each presentation. An index of ear advantage was computed for each subject on each tape (*17*).

The scores from the six ability tests were transformed to z-scores within each age grouping to permit comparisons between tests and age groupings. Factor analysis for the entire sample indicated that the tests could be assumed to measure separate verbal and spatial factors. Therefore, the mean of the three verbal scores and the mean of the three spatial scores were used for further computations. A difference score, the verbal score minus the spatial score, represented intraindividual strengths and weaknesses independent of overall intelligence. The correlation between difference scores and IQ was very small ($r = -.14$). Two scores were used in the analysis of the dichotic listening data. The mean of the index scores on the two tapes indicated both the direction and magnitude of lateralization, and the mean of the absolute values of the index scores indicated magnitude independent of direction. A three-way, sex by maturation by age level, analysis of variance was computed for the verbal, spatial, difference, and lateralization scores.

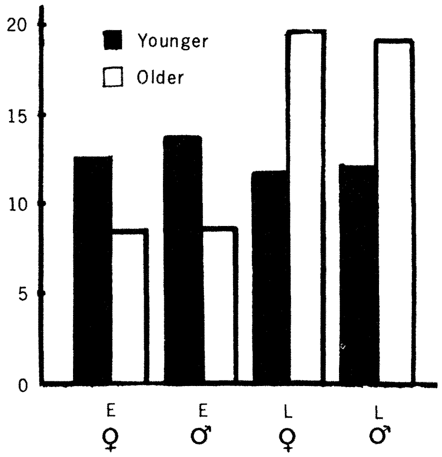

Fig. 2. Absolute values of mean percent ear advantage (lateralization) scores for each grouping of sex, maturation, and age level.

As was predicted, within individuals and regardless of sex, early maturers scored better on verbal than spatial tasks, and late maturers scored better on spatial than verbal tasks ($P < .001$) (Fig. 1). The earliest maturing group (early maturing girls) and the latest maturing group (late maturing boys) showed the greatest differences ($P < .001$). However, the difference score represented a dissociation between the spatial scores, which were systematically related to rate of maturation ($P < .001$), and the verbal scores, which showed no relationship to rate of maturation. Sex differences, although in the predicted direction, did not reach a conventional level of significance.

To control for the possible effect of chronological age, a two-way, sex by maturation, analysis of variance was computed for the 13-year-old group only. Again, the difference scores were systematically related to maturational rate ($P < .03$), and sex differences, although in the predicted direction, did not reach a conventional level of significance.

Late maturers showed larger ear advantages than early maturers in the older but not in the younger group for both dichotic measures ($P < .02$; Fig. 2), and there were no sex differences. The extreme-groups design did not permit a valid correlation between scores of degree of lateralization and those of mental ability to be computed; however, that the group showing a greater degree of lateralization was also superior in spatial ability supports the Levy position (*5*) against that of Buffery and Gray (*4*).

The striking relation between rate of physical maturation (independent of sex) and spatial ability, verbal-spatial patterns, and lateralization has several important implications. First, sex accounted for only a very small proportion of the variance in comparison to maturational rate. Therefore, reported sex differences in these behaviors probably reflect the differential distribution of the sexes along a physiological continuum more than a categorical difference between male and female. This concept might also apply to other behaviors not examined in this study. Second, since maturational rate was shown not to be related to verbal ability, the sex differences in verbal and spatial abilities may have very different etiologies and cannot be explained by a common set of causes, whether environmental or constitutional. Finally, rate of maturation (or its implicit physiological correlates) may play an important role in the organization of higher cortical functions.

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→ H. A. Witkin, *J. Pers.* **19**, 1 (1950). The child must find a simple design hidden in a complex one and time to solution is recorded.

15. The child is asked to indicate which of a series of figures can be rotated to match a stimulus figure (*12*).
16. Dichotic listening is a technique in which two sounds are presented simultaneously, one to each ear. These, however, are not perceived as simultaneous and it is assumed that the discrepancy is a function of lateralization. The

sound presented contralaterally to the dominant hemisphere tends to be perceived first. See also D. Kimura [*Can. J. Psychol.* **15**, 166 (1961)].

17. The number of correct identifications of stimuli presented to the right (R) and left (L) ears are entered into the formula $(R - L)/(R + L) \times 100$. as described by M. Studdert-Kennedy and D. Shankweiler [*J. Acoust. Soc. Am.* **48**, 579 (1970)].
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Reproductive Development in a Female Songbird: Differential Stimulation by Quality of Male Song

Abstract. *Female canaries exposed to playback of large repertoires of male songs built nests faster and laid more eggs than did those females exposed to smaller song repertoires: females are attentive to attributes of male song, and their choices have played a role in the evolution of oscine singing behaviors.*

The vocalizations of male birds, in addition to repelling other territorial males, attract and stimulate mates. Darwin (*1*) championed the "melody of voice" as functioning in the "charming of females," and enhancement of female reproductive development by male sounds has subsequently been demonstrated (*2*). With females exerting the choice in mate selection (*3*), female discrimination is implicated as a significant selective force in the evolution of the bewildering diversity of male singing behaviors that exist among the songbirds. I now report that female reproductive behavior is differentially stimulated by variations in the complexity of intraspecific song.

The experimental subjects were selected from an inbred strain of Belgian "Wasserschlager" canaries (*Serinus canarius*). In these birds, a typical male song repertoire consists of 30 to 40 distinct note patterns or syllables. Four 10-minute experimental tapes were prepared by selective editing of a large number of recordings of natural canary song. Two tapes had large song repertoires of approximately 35 syllable types, and two had small song repertoires of only five syllable types (*4*). For the two with large repertoires, 15 songs averaging 30 seconds in length were selected from tapes of each of two normal males. For each of the tapes with smaller song repertoires, songs of a normal male were searched for five naturally occurring sequences of five different syllable types (for example, ABCDE), chosen because of their relatively high frequency of occurrence in the songs; these sequences were edited and spliced together in random order to make 15 different 30-second songs. Because of inequalities in total song lengths in the different categories, a final editing of tapes yielded, in the two small-repertoire tapes, 14 songs totaling 450 seconds and 15 songs totaling 441 seconds, and in the two large-repertoire tapes, 14 songs totaling 439 seconds and 15 songs totaling 447 seconds. The 14 or 15 songs for each experimental tape were then spliced together, with 10 seconds between songs, to form singing bouts.

During September and October 1974, 24 virgin female canaries were selected for uniformity of age (6 to 7 months) and gonadal development (the largest follicle size was ≤ 0.4 mm). On 17 December four treatment groups were established, with siblings distributed among the groups. The six birds in each group were paired randomly. Each pair was housed in a metal canary cage (27 by 28 by 52 cm); a partition divided the cage between the two birds and allowed auditory but not visual contact. Each of the 12 cages was placed in a sound attenuation chamber (IAC model AC-1) equipped with loudspeakers. To prevent the birds from looking at themselves (*5*), the reflective interior window of each chamber was covered. Day lengths prior to 17 December were natural, but during the experimental period, the light : dark cycle was constant (9.5 : 14.5).

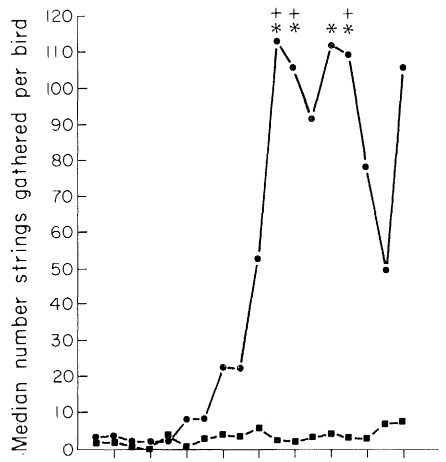

Fig. 1. The median number of strings gathered by 12 female canaries exposed to either large (●) or small (■) male song repertoires. There were significant differences between the two groups during period 11, 12, 14, and 15 (Mann-Whitney U test; *; $P < .05$; *+, $P < .025$).

At 1200 hours on 21 January 1975 (day 1 of the experiment), each bird was supplied with a metal-wire nest cup and a bundle of 75 10-cm strings attached to the side of the cage. Each day at 1200 hours, all eggs that were laid and all strings that were pulled from the bundle and left on the cage floor or placed in the nest cup were removed and counted; the string bundle was then replenished to 75 strings. Gathering of strings from a dispenser is a sensitive assay of reproductive development, for, in photoperiodically induced reproductive development in female canaries, string gathering is highly correlated with the diameter of the largest ovarian follicles and with oviduct weight, and the latter is highly correlated with plasma levels of luteinizing hormone (*6*).

Even though recorded songs had not yet been played on day 6, three females were building feverishly (*7*), and one female laid an egg. A fourth female began gathering all 75 strings on day 7. Beginning at 1200 hours on day 7 and continuing through day 36, the females were exposed to the 10-minute male song bouts 12 times during 3-hour periods in the morning and in the afternoon. The group including the female that laid an egg on day 6 was intentionally placed in the small song repertoire group (*8*). Subjects for the other three treatment groups were selected at random.

String-gathering scores were tabulated for 36 days, 6 preceding and 30 during exposure to songs. Individual string-gathering scores were summed over successive 2-day periods. By days 21 to 22 (period 11) the median number of strings pulled by the 12 female canaries exposed to the larger song repertoires significantly exceeded the number pulled by the 12 canaries exposed to the small song repertoires (Fig. 1). Even if the three or four birds exhibiting high string-gathering scores prior to their exposure to the song stimuli are culled from the experiment, the difference between the groups remains statistically significant (*9*). Correlated with the high levels of string gathering were higher levels of egg laying. By day 36 of the experiment, five females exposed to the larger song repertoires had laid 15 eggs, while two birds exposed to the smaller song repertoires had laid only five eggs; monitoring of eggs (but not